
Results of GEAE HSCT Propulsion System Studies

First Annual High Speed Research Workshop

May 15, 1991

Williamsburg, Virginia

Fred H. Krause
HSCT Project
GE Aircraft Engines



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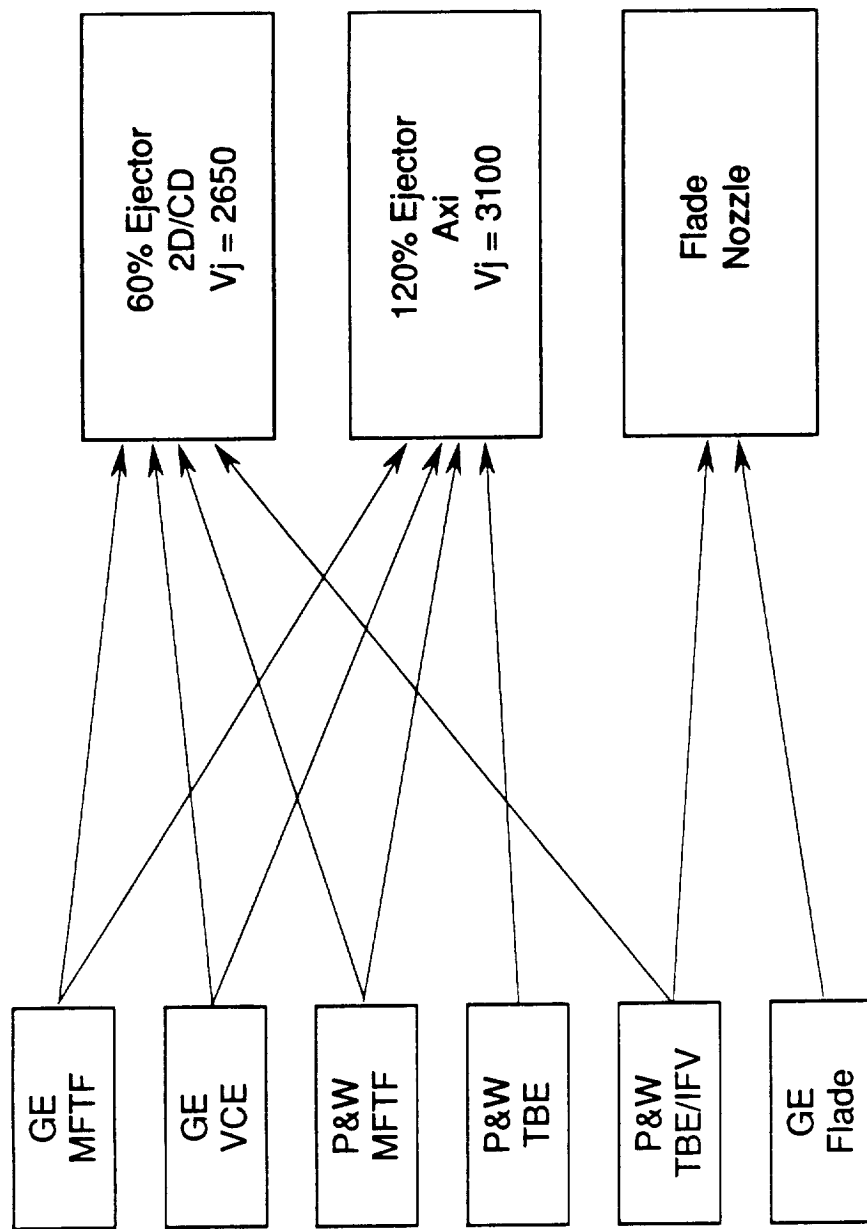
Good Afternoon. I've got good news and bad news. First the good news; I am not going to talk about emissions or sonic boom. The bad news is, that I will talk about acoustics.

This afternoon I am going to give you a very brief overview of the results of GE's HSCT propulsion system design studies. I will also cover our plans for the remainder of this year. A large part of my presentation revolves around the acoustic nozzle design and its impact on the propulsion system performance. Our studies have shown that this component is a key driver on the HSCT propulsion and aircraft system designs. Cruise Cfg, acoustic performance, nozzle weight, and takeoff Cfg are all critical nozzle design features.

HSCT Engine and Nozzle Options - Being Evaluated

P&W and GEAE are evaluating a number of engine concepts, the mixed flow turbofan (MFTF), the variable cycle engine (VCE) (double bypass engine), the turbine bypass engine (TBE), the turbine bypass engine with inverted flow value (TBE/IFV), and the fan on blade (FLADE). Three different exhaust nozzle concepts, one with 60% ejector flow, one with 120% ejector flow, and a fluid shield type nozzle for the FLADE, are being evaluated. Engine cycle studies are being conducted at Mach 2.4 and Mach 2.0 with both NASA and company funding.

HSCT Engine and Nozzle Options – Being Evaluated



Between GE and P&W We are Covering All Options

This is just a quick look at the systems studies GEAE is performing this year both under IR&D and NASA contract. The first three items are an example of the way our IR&D and contract studies compliment one another. The first line represents our Flade Cycle and flowpath studies for 1991. We have selected a baseline cycle and flowpath for the Flade concept under NASA contract this year. We will continue to look at Flade performance with alternate airflow schedules for the next 5-6 months. Mean while, under our IR&D studies we will conduct a mechanical preliminary design of this engine. Starting in July, we plan Flade nozzle design studies under NASA contract. During the first three months of this year we did some MFTF precursor studies under overhead funding. Now we are on contract for the cycle/flowpath and mechanical design of a Mixed Flow turbofan for HSCT.

Again, with the VCE we will do cycle/flowpath trade studies under NASA contract and the preliminary mechanical design under IR&D.

Under our UPS contract we are conducting an axisymmetric exhaust nozzle trade study for high specific thrust engines. This morning Muni Majjigi talked about our 2-D suppressor ejector nozzle design. Under this task order we are trying to apply what we learned in the design of the 2-D nozzle to axisymmetric nozzle designs. I will briefly show some of the results of that task and I think Marty Smith of Pratt will have a few words to say about 2-D vs. Axi acoustic nozzle designs.

GE HSCT – Systems Studies

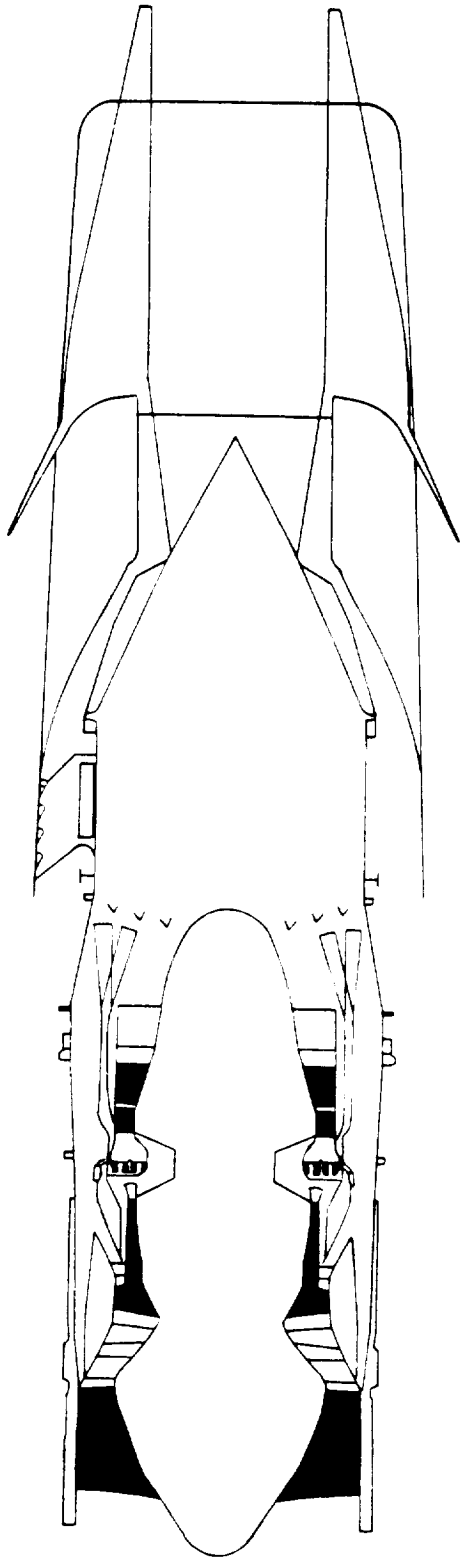
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
• Blade cycle/flowpath												
• Blade mechanical design												
• Blade nozzle PD												
• Mixed flow turbofan												
• Update VCE												
• VCE mechanical design												
• Axi-exhaust nozzle trades												
• GE/NASA nozzle installation												
• Inlet studies												
• Control system payoff studies												
• Control system definition												

Between NASA Contract and IR&D GEAE Will Generate the Data Needed for Downselect

GE Variable Cycle Engine

The GE variable cycle engine is a double bypass engine with an overall pressure ratio of 25 and a bypass ratio of 0.65. The data shown is based on earlier design groundrules. We are in the process of updating this design to reflect the common design groundrules. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment.

GE Variable Cycle Engine

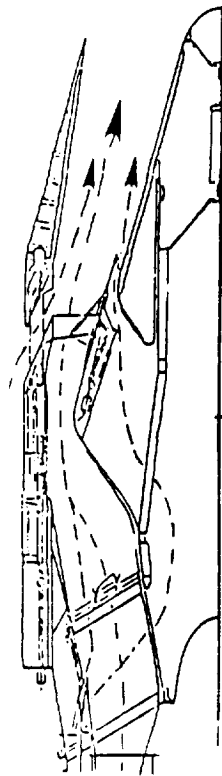


FPR	4.8	SFC subsonic	.90
PROA	25	SFC supersonic	1.24
BPR	0.65	T41 cruise	2750°F
Weight	- Core	T3 cruise	1200°F
	- Exhaust nozzle	Cfg cruise	.986
	- Total	Cfg takeoff	.93

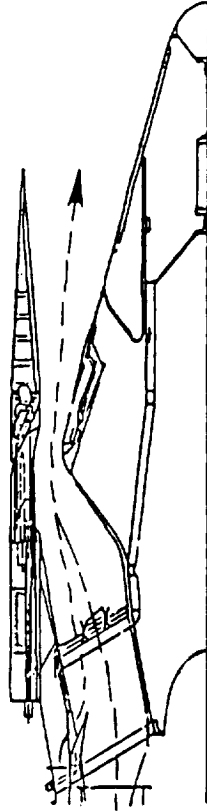
This data is based on GE design ground rules. Engine design is being updated in 1991 to common design groundrules

This chart shows our basic axisymmetric acoustic nozzle design. It represents the final nozzle design from our AST studies and the starting point for HSCCT work. The four primary operating modes are shown. In the take off mode, the ejector flap is slid aft to open the ejector inlet. Some flow from the fan duct is brought down through the struts and into the plug where it exists tangentially to the core flow in the divergent section of the nozzle. All of the core flow and the rest of the fan flow mix and exit the main nozzle between the chutes which are hopefully filled with ambient air. Our goal for this nozzle is 60% flow entrainment. In the AST days the A8 of this nozzle was limited such that during acceleration some of the fan flow had to exit through the plug. This could give us on Inverted Velocity Profile type noise reduction 3-5dB during the climb out/acceleration flight regimes without opening the ejector. In the supersonic cruise mode the nozzle operates like a standard plug nozzle. A8 is varied by sliding the ejector flap fore and aft and A9 internal can also be varied by changing the ejector flap angle. In the reverse mode, the ejector flap moves all the way aft exposing the reverser guide vanes and a blocker door drops down to close off the primary nozzle.

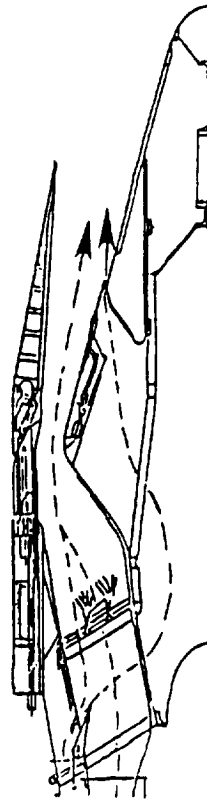
Coannular Nozzle With 20 Chute Suppressor and Ejector Operating Modes



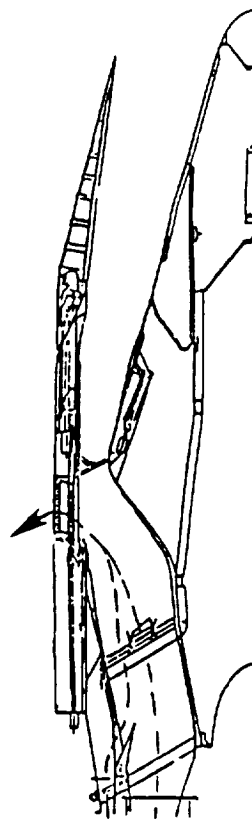
Takeoff



Supersonic Cruise



Acceleration



Reverse

The Final AST Nozzle is the Starting Point for Current HSCT Work

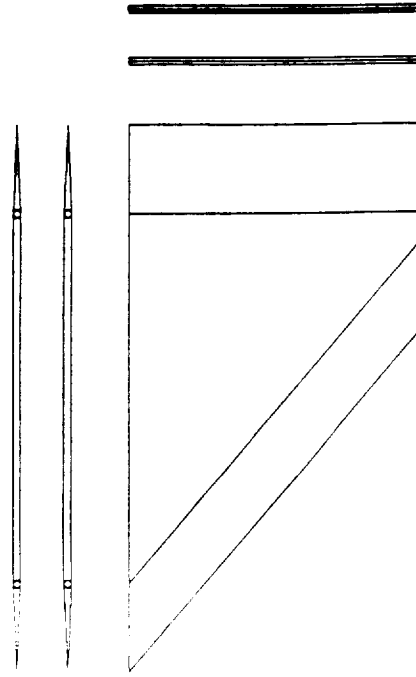
One of the areas that we are exploring under our axi exhaust nozzle trade studies is innovative chute design. A key to getting 60% flow entrainment is suppressor area ratio, which is the ratio of the total area at A8 to the core flow area at A8. We would like the chute exit area to be twice that of the core flow. It is impossible to stow such large chutes in a plug like I showed on the last viewgraph unless they have variable geometry. The collapsing chutes on the right hand side of this chart might be stowable out of the core stream during the other operating modes, but they are obviously complex and heavy.

The chute design on the left hand side of the screen would always be in the stream, but the leading edge would close during suppressed operation. For the other flight conditions it would be open with flow going through it. It would obviously want to be located in a low mach number flow region of the nozzle.

Both of these approaches are complex and heavy and hopefully won't be required.

Innovative Chute Design

Opening chutes



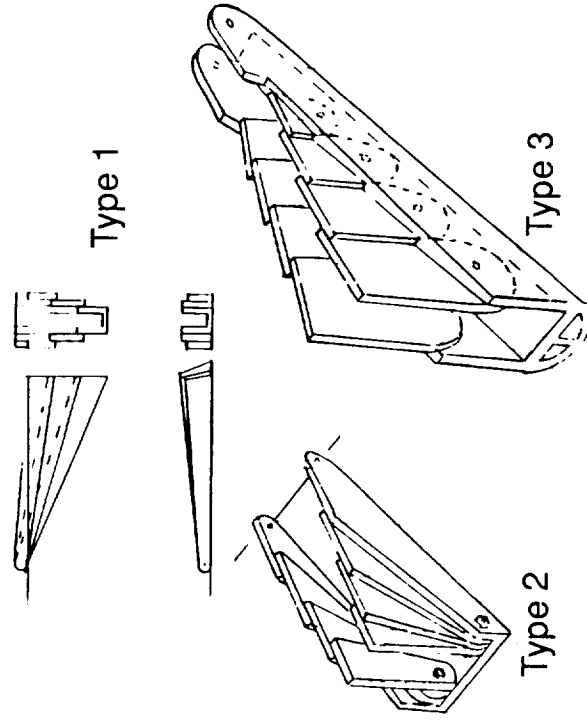
Advantages

- Stowage area
- Blockage ratio
- Complex shapes

Disadvantages

- Weight
- Actuation
- Performance

Collapsing chutes



Advantages

- Stowage area
- Chutes out of stream
- Blockage ratio

Disadvantages

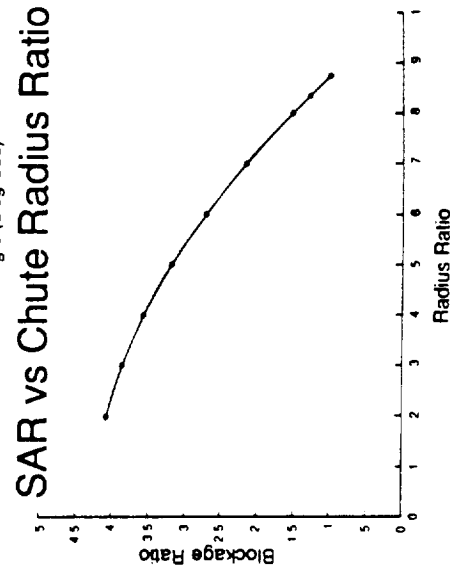
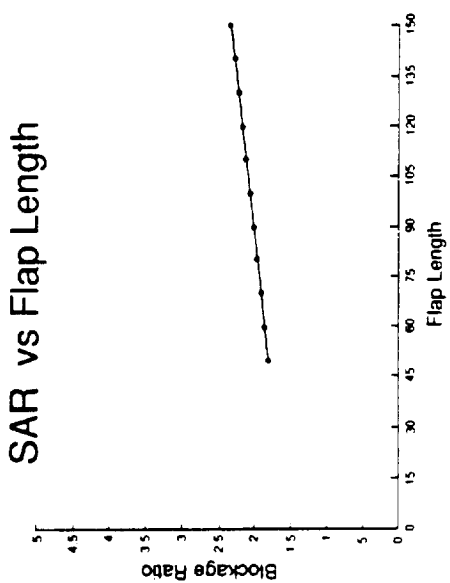
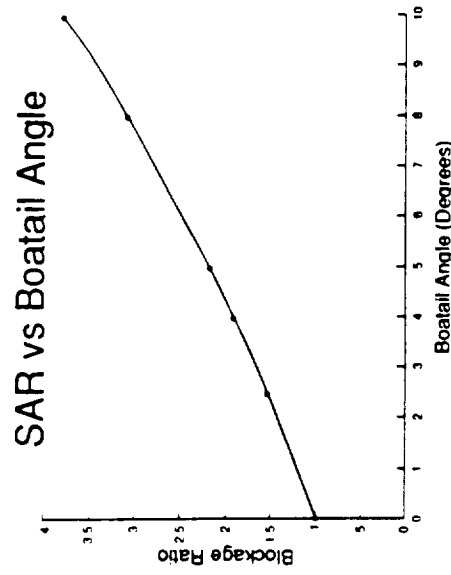
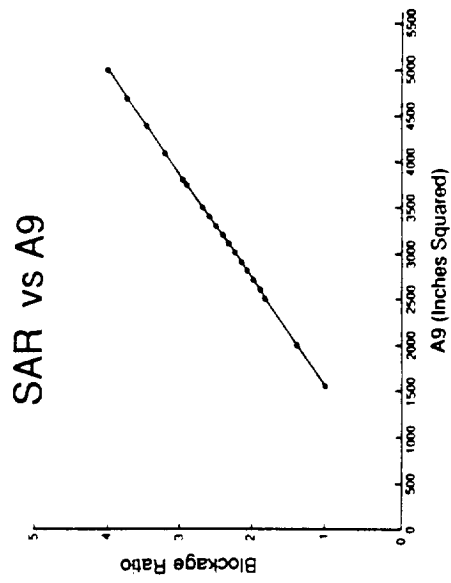
- Weight
- Actuation
- Performance
- Simple shapes

Complicated and Heavy . . . Hopefully They Won't be Necessary

This chart shows some very early results from our trade studies on a baseline nozzle which is similar to the AST type nozzle I showed a couple of charts ago. The first plot shows suppressor area ratio versus A9. A9 is obviously limited by what is required for reasonable supersonic cruise performance. We will generally accept a small cruise perf penalty for a slightly larger SAR. Ejector flap length has a small but positive influence on stowable suppressor size. But again flap length is limited by weight and performance considerations. Fixing all the nozzle design parameters except boattail angle we see that boattail angle has a significant impact on SAR but boattail angle is limited to 2.5 to 4.0 degrees for reasonable supersonic nozzle performance. The final plot is really a plot of chute radius ratio vs SAR. Chute radius ratio is the chute radius to the top of the chute divided by the radius to the bottom of the chute. A practical limit is out here about 0.6 - 0.7.

We will be doing sensitivities for aero performance, acoustics and weight for these same geometric design parameters.

Axi Acoustic Design Trade Studies



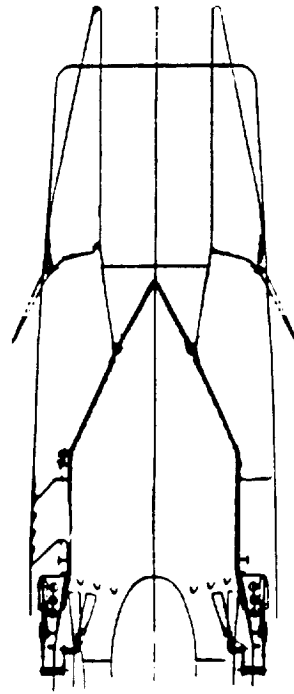
GEAE is Bounding the Geometric Problem

This chart is a look at our current 2-D suppressor ejector nozzle. Mr. Majjigi described this nozzle and its anticipated aero/acoustic performance in some detail during this morning's source noise session. The nozzle as designed has a suppressor area ratio over 2.5 with convergent divergent chutes. We anticipate that it would pump an additional 60% (of the engine flow) through the ejectors and into the exhaust nozzle. In the upper left hand corner of the figure the nozzle is shown in its take off position with the chutes deployed fully. The chutes may be retracted partially for conditions where A8 required is larger. In all other modes the chutes are retracted. In the supersonic mode the boattail angle is $\sim 4^\circ$ and the nozzle is slightly expanded beyond the optimum area ratio for internal performance.

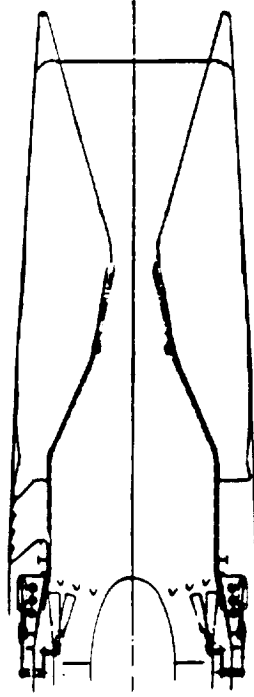
In the subsonic mode the boattail angle approaches 15° . I should point out that the secondary flaps shown here are 80 inches long.

In the thrust reversing mode the nozzle closes at the throat and the reverser doors are opened exposing the reverser vanes. With all of these operating modes and control variables accurate geometry control will be critical to maximizing performance at cruise and noise suppression at take off.

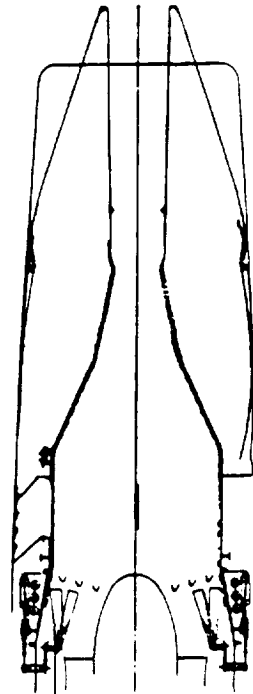
2DCD Nozzle Operating Modes



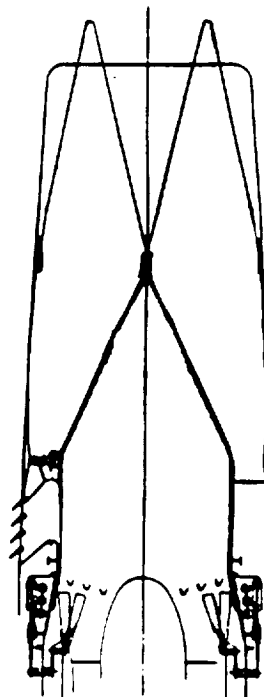
Takeoff



Supersonic



Subsonic



Thrust Reversal

*Accurate Geometry Control Critical to Maximizing Performance
at Cruise and Maximizing Noise Suppression at Takeoff*

GE is still trying to evaluate both axi and 2-D nozzle concepts. There are advantages and disadvantages to both types. This chart highlights some of the advantages/disadvantages of 2-D nozzles as compared to axi nozzles.



Unfortunately at this point we have not had an airframe manufacturer evaluate the installation benefits on one type versus the other.

2D vs Axi

Advantages

- Increased perimeter
- Suppressor area ratio
- Variable A8
- Acoustic treatment surface area
- Manufacturability

Disadvantages

- Structure weight
- Ejector inlet area
- Leakage/performance loss

Installation?

Both Concepts Will Continue to be Evaluated

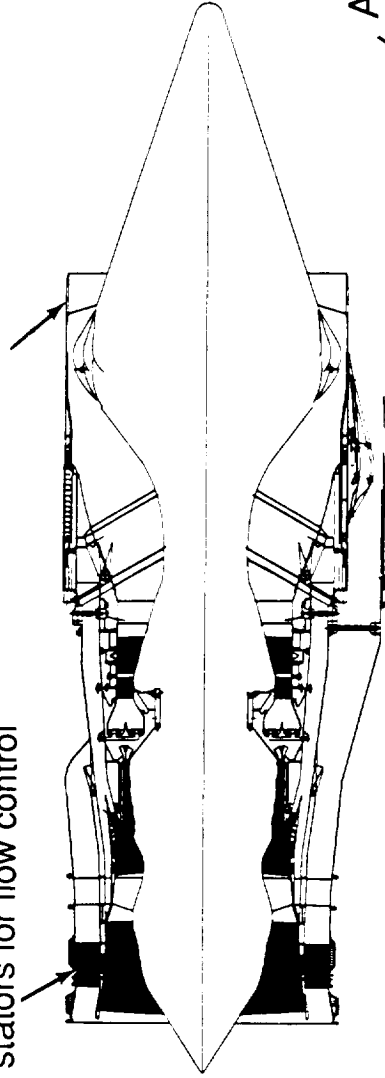
Several speakers over the past two days have talked about multiple approaches to the noise reduction problem. The first being complex high flow entrainment suppressor ejector nozzles that entrain 60-120% additional ambient air into the nozzle, thus reducing the mean jet velocity in a high specific thrust engine. The high flow engine is another approach. Most of you are familiar with the Rolls Royce Tandem Fan concept. This is GE's approach. The Flade or Fan on Blade engine augments flow during take off and subsonic flight regimes (climb, acceleration and cruise) resulting in a higher bypass engine. The Flade is attached to the second fan stage and is driven by the LP turbine. Variable inlet guide vanes regulate the flow into this stage ala the convertible engine concept which GE developed and tested for the DARPA X-Wing program.

Some minimum amount of flow must go through the Flade stage even in supersonic flight regimes but inlet boundary layer bleed air would probably be used resulting in an installed engine performance improvement.

Another feature of the Flade propulsion system is the fluid shield nozzle concept. The Flade flow is collected in an annular duct which wraps around the bottom 200° of the engine to form an acoustic shield. The shield provides additional noise reduction, beyond the noise reduction which results from the much lower mixed jet velocity required to make the thrust with the larger mass flow of the Flade engine.

GEAE "Flade" HSCT Propulsion Concept Low Noise Geometry Setting Shown

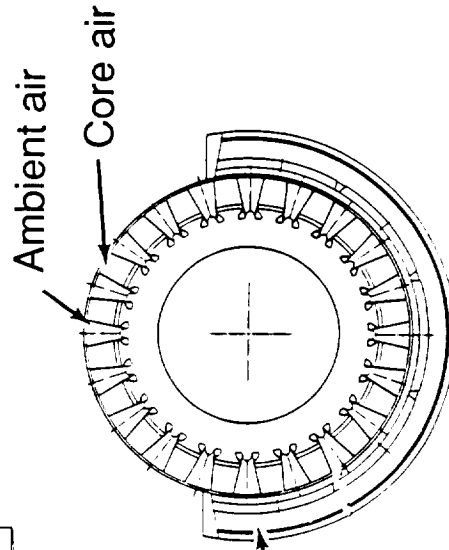
- High flow Fladed fan concept
 - Variable stators for flow control
- Simple suppressor



- Minimum Flade flow during supercruise
 - Inlet boundary layer air could be used
 - C/D nozzle shape for best supercruise performance

- For low noise takeoff

- Flade flow used to form an acoustic shield for additional noise reduction

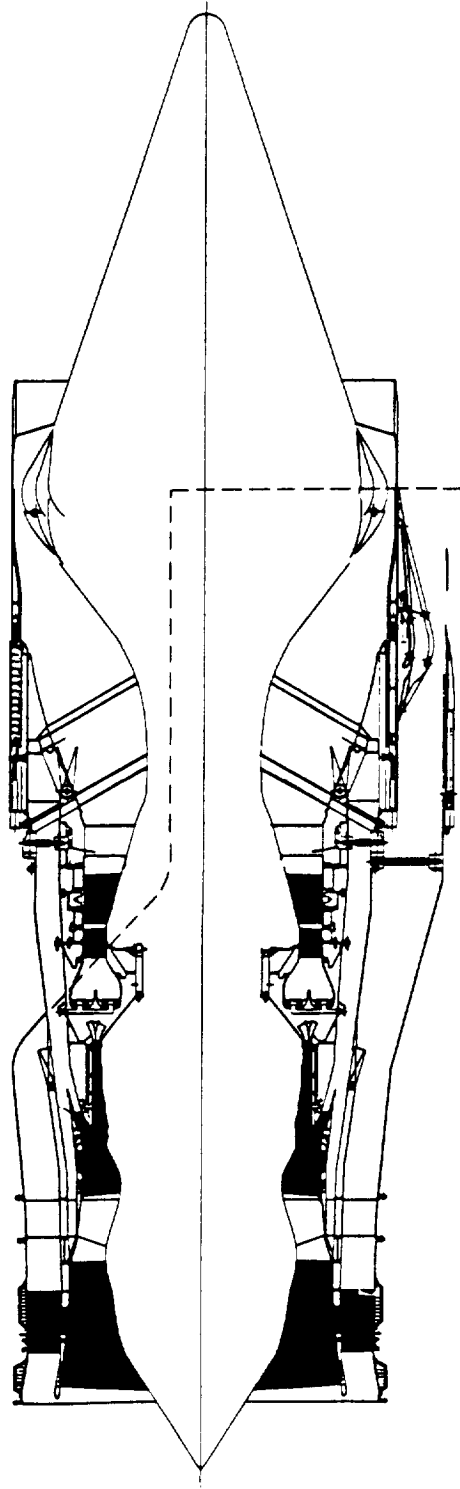


GEAE's High Flow Concept Beats the Noise Problem

GE Fan on Blade (Flade)

The data shown on this page reflects the latest GE Flade designs based on the joint GE/P&W HSCT propulsion system design groundrules. The air flow of the basic core VCE engine is 650 pps. While the Flade pumps an additional 250 pps. A unique feature of the Flade concept is that the core engine is sized/ designed for supersonic cruise while the flade is sized/ designed for takeoff conditions. An axisymmetric exhaust nozzle with variable exit areas and minimum suppression on the core flow is being used.

GE Fan on Blade Engine (Flade)



FPR	4.95	SFC subsonic	0.92
PROA	21.7	SFC supersonic	1.31
BPR	0.33	T41 cruise	2600°F
Flade PR 1.8		T3 cruise	1180°F
Weight	- Core	Cfg cruise	.982
	- Exhaust nozzle	Cfg takeoff	.95
	- Total		
			11,985

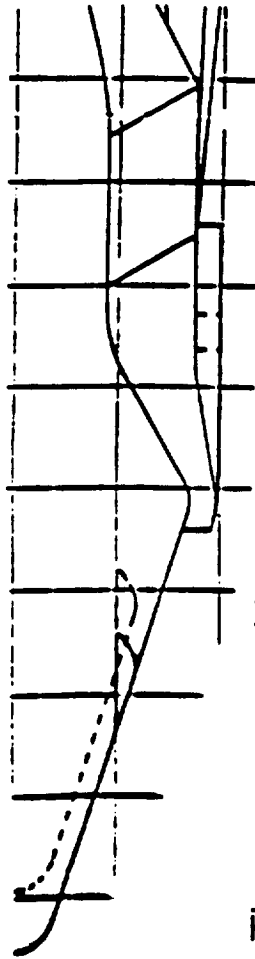
This chart depicts 3 nozzle concepts which we studied for the Flade. The first concept we studied was a two stream exhaust where all of the Flade flow was ducted through the struts into the plug and out parallel to the core flow. This results in an inverted velocity profile which could be worth 4 dB of suppression. This amount of suppression could be enough if you had a modest take off thrust requirement and a large flade flow. The problem is that this nozzle is large and heavy.

The second approach which we tried was a 3 stream nozzle without a suppressor but with the fluid shield. The fluid shield is shown on the bottom and it would wrap around the bottom 200-230 degrees of the nozzle. The fan flow is ducted through the plug. This concept is the simplest and lightest, but it was still not quite good enough from an acoustics perspective.

The final concept is a fluid shield with suppressor chutes but no ejector flaps as Sam mentioned in the GE/P&W summary talk yesterday. This nozzle weigh about 15% more than the second concept, but it does meet the Stage III noise goals.

Acoustic Nozzle Options Studied

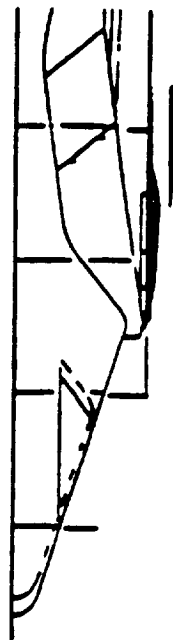
Two stream



Weight = 6,620 lb

- Flare through plug
- Simplest/largest
- ≈ 4 dB

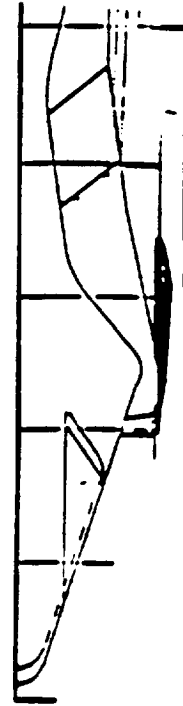
Three stream without suppressor



Weight = 3,980 lb

- Fan flow through plug
- Fluid shield ≈ 3 dB
- IVP ≈ 3 dB

Three stream with suppressor



Weight = 4,565 lb

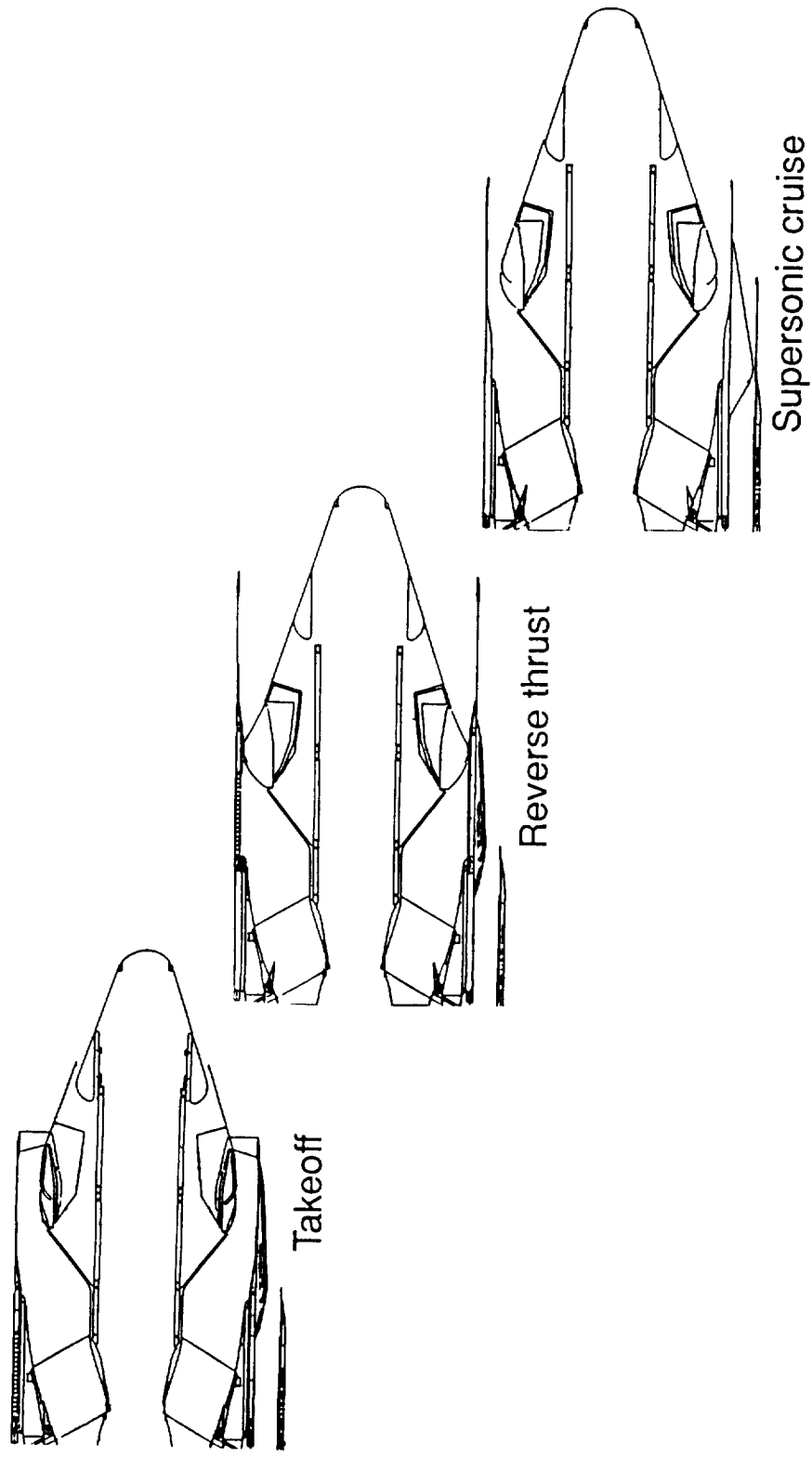
- Fan flow through plug
- Fluid shield ≈ 3 dB
- IVP ≈ 3 dB
- Suppressor chutes ≈ 5 dB

All Flare Nozzles Capize on Low V_{javg}

Three Flade operating modes are depicted here. The first - takeoff I have described previously. The second is reverse thrust. In this mode the plug expands to seal the aft nozzle exit at the throat and the outer duct slides aft to expose the reverser cascades. Note that the reverser uses only the 120-140° circular arc around the top of the nozzle so that the reversed thrust does not have to go through the Flade duct.

In the supersonic cruise mode the outer duct fore/aft position controls A9 internal for maximum nozzle performance.

Flade Nozzle Operating Modes



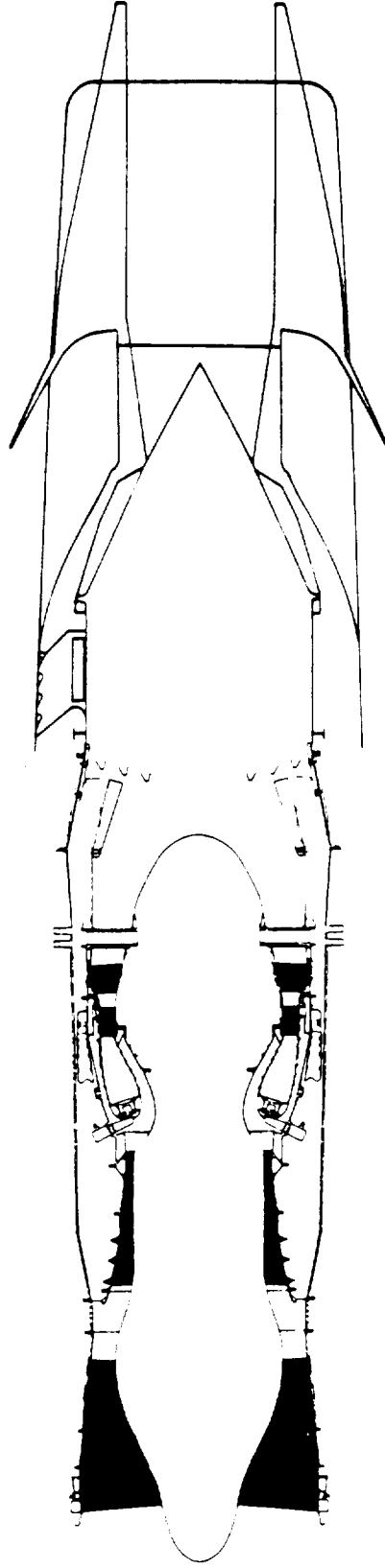
*The Lack of Ejector Flaps on the Flade Nozzle
Reduces Weight and Complexity*

GE Mixed Flow Turbofan

Recently GE has agreed with Pratt to study mixed flow turbofans. We have selected this engine type to be a test case for comparing our design methodologies and will eventually agree on a cycle to be designed by both companies. We can then compare flowpath and mechanical design results.

The current GE mixed flow turbofan engine is a low bypass ratio turbofan with an overall pressure ratio of 21.5. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment. Nozzle thrust coefficients are based on this exhaust nozzle. The cycle and preliminary design activity on this engine is due to be completed in the next few months.

GE Mixed Flow Turbofan

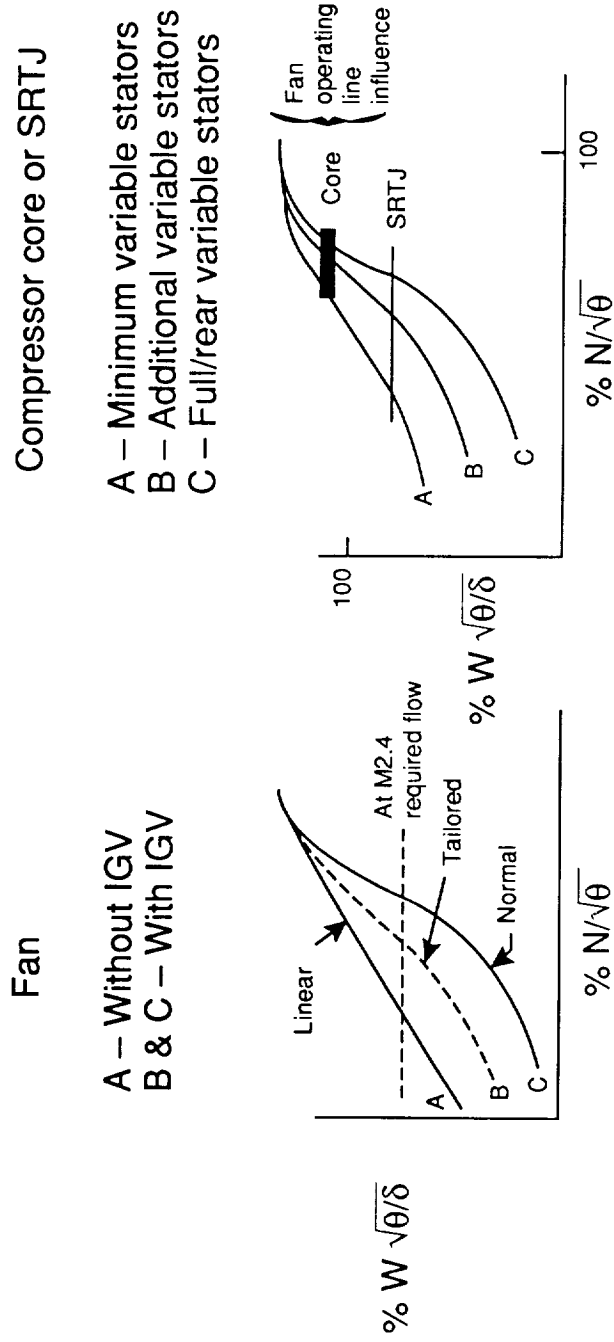


FPR	4.75		SFC subsonic	TBD
PROA	21.5		SFC supersonic	TBD
BPR	0.15		T41 cruise	TBD
Weight	- Core	TBD	T3 cruise	TBD
	- Exhaust nozzle	TBD	Cfg cruise	.982
	- Total	TBD	Cfg takeoff	.95

SUMMARY CHART UNAVAILABLE AT TIME OF PUBLICATION

Compression System Characteristics

- Will set max percent rpm (105-110-115+)
- Will impact no. stages, turbine radius, weight, etc.



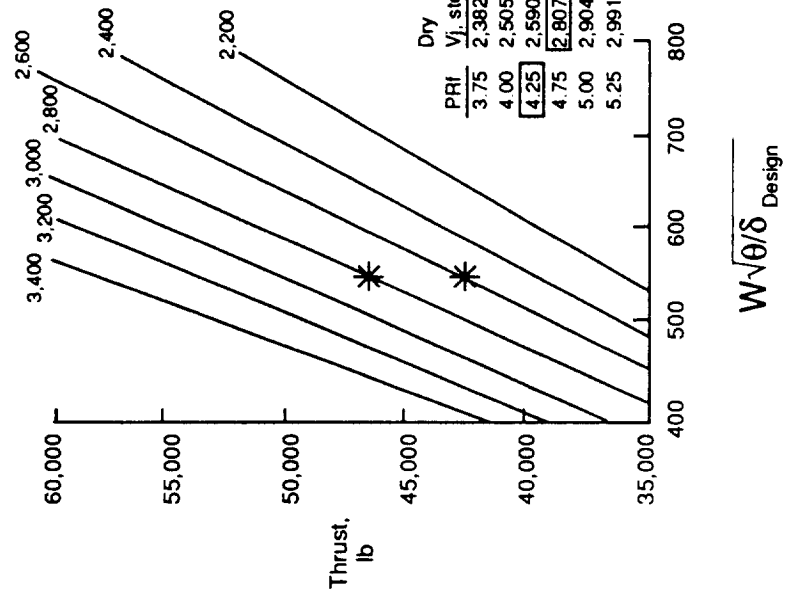
*Compression System Characteristics Are
A Key to the MFTF Design*

Our preliminary turbofan cycle studies are looking at the impact of take off acoustics and thrust requirements at the sideline measuring point and top of climb on the design fan pressure ratio, bypass ratio and airflow size. The right hand plot shows thrust versus airflow for lines of constant jet velocity. If we enter this plot with a jet velocity limit at which we think that we can meet Stage III noise requirements, we can pick off a minimum airflow size. In this case, let's assume we feel comfortable that with our suppressor nozzle we can meet Stage III with a V_j of 2700 fps and that the thrust required is 38,000 lbs. We would determine that a 530 pps engine with a fan pressure ratio of 4.25 would meet the requirements. With this engine we would have no dry thrust margin so we would pick a FPR of say 4.75. This gives us the capability to push the throttle to a V_j of 2921 fps which could give up another 4,000 lbs of thrust.

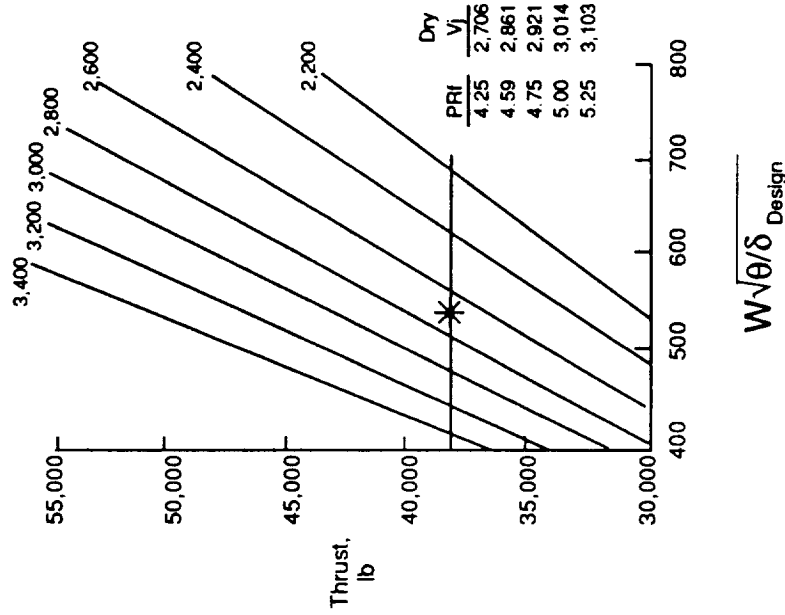
Preliminary Turbofan Studies

At SLS – standard day
 V_j – comp. exp

Cfg = 0.95



At 0.322/689' +18°
 V_j – comp. exp

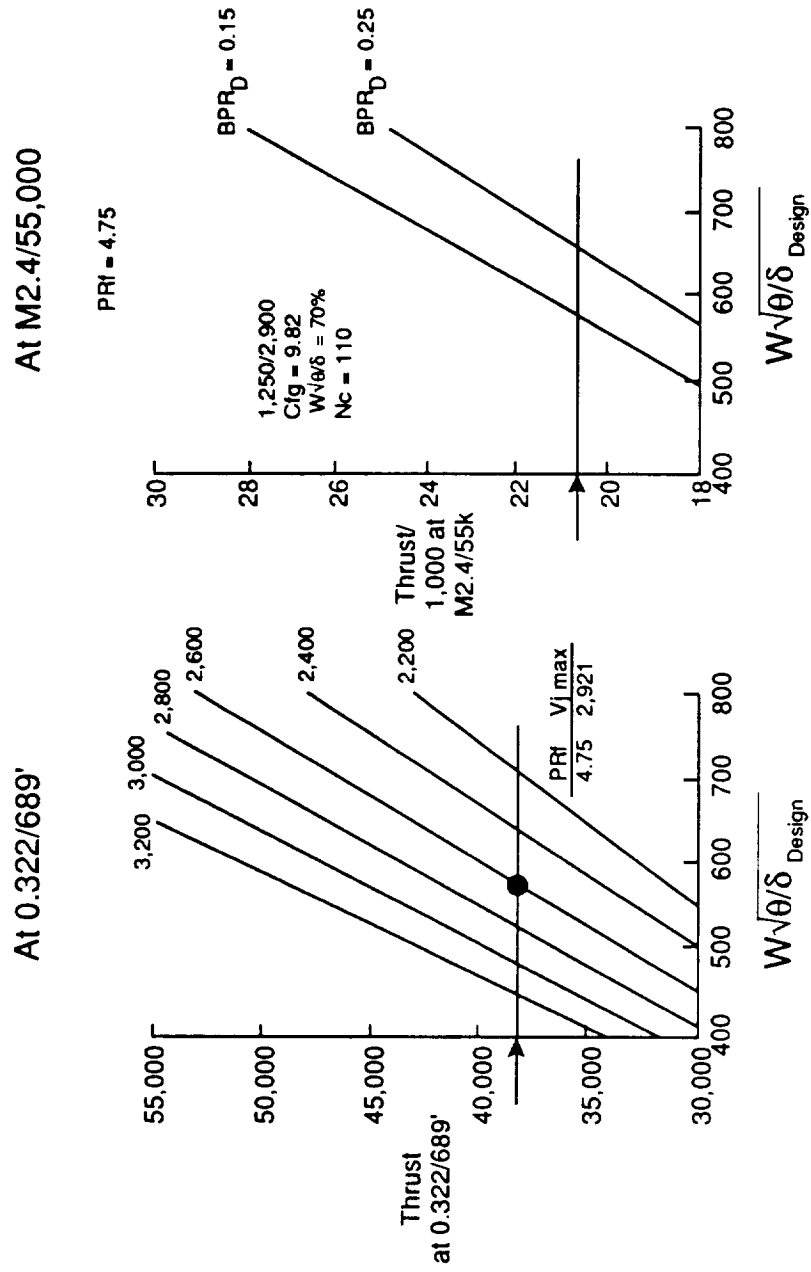


Acoustic Requirements Drive the Design at Takeoff

The plot on the right shows how the Design Bypass Ratio along with the top of climb thrust requirement size the engine for a given fan pressure ratio. Assuming that the top of climb thrust requirement is 20,750 lbs for a $BPR_D = 0.15$ the engine needs to be about 550 pps. Slightly larger than the take off requirement from the previous chart but a good match. For a design BPR of 0.25 the required engine size grows to 650 pps and the takeoff thrust available would be substantially more than the requirement.

Our studies to date on this type of engine have been limited, but we are working with P&W and NASA to find the best MFTF design and compare it to the other candidate propulsion systems.

Preliminary TF Studies PRf = 4.75, BPR



*Top of Climb Thrust and Design Bypass
Ratio Size the Engine*

I think that the conclusions chart is reasonable self explanatory. The bottom line is. We are not ready to select an engine concept yet, but within the next year and one half, our propulsion system studies and acoustics tests should put us in a position to eliminate several concepts.

Summary

- GE/P&W have agreed on a reasonable set of design ground rules
- GE/P&W exploring wide range of propulsion system and nozzle options
- Cycle and flowpath trade studies are key to evaluating concepts
- Mechanical design trade studies are oriented towards meeting subsonic commercial engine life with a supersonic engine
- By this time next year the results of the design trade studies, the acoustic tests, the emission testing and aircraft sizing studies should help answer the three challenges
 - Noise
 - Emissions
 - Economics

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